Proc. NIPR Symp. Antarct. Geosci., 3, 1–12, 1989

SEISMIC OBSERVATION WITH LOCAL TELEMETRY NETWORK AROUND SYOWA STATION, EAST ANTARCTICA

Junpei AKAMATSU[1], Nobuo ICHIKAWA[1] and Katsutada KAMINUMA[2]

[1]*Disaster Prevention Research Institute, Kyoto University, Gokasho, Uji 611*
[2]*National Institute of Polar Research, 9–10, Kaga 1-chome, Itabashi-ku, Tokyo 173*

Abstract: A local telemetry seismic network was established around Syowa Station to study local seismicity and characteristics of seismic waves in the Lützow-Holm Bay and Prince Olav Coast region, East Antarctica. The observation system utilizes an event detection algorithm for monitoring small earthquakes by coping with noise condition peculiar to Antarctica.

More than 4400 events were recorded during the period from June 1987 to January 1988. Most of them were icequakes and continuous vibrations caused by glacier movements. However, 477 earthquakes were identified.

Several shallow crustal earthquakes with *S-P* times of 5–6 s and 20 s are located around Syowa Station, near possible faults inferred from surface topography and geology. Although the East Antarctic shield has long been considered to be an aseismic area, local earthquakes occur under some tectonic condition.

1. Introduction

The East Antarctic continent is well-known as one of the most aseismic areas in the world (*e.g.*, KOGAN *et al.*, 1965; ADAMS *et al.*, 1985). The seismicity around Syowa Station in Lützow-Holm Bay was reported to be less than one micro earthquake per month, by the routine seismic observation carried out at the station (KAMINUMA, 1976). However, the source locations are not determined because of the inevitable difficulty coming from the single station observation. Therefore, a suitable local network has been considered necessary to study seismic activity in relation to the Antarctic tectonics.

Attenuation of seismic wave and source property have been discussed in relation to seismic activity in many regions of various tectonic conditions (*e.g.*, AKI, 1989; AKAMATSU, 1980, 1986). Attenuation in the East Antarctic shield is thought to be extremely small. The explosion seismic experiments reveal that the *P*-wave velocity of the surface layer in East Ongul Island is about 6 km/s; the value nearly corresponds to the upper crustal velocities just beneath the ice sheet in East Antarctica (ITO *et al.*, 1984). Therefore, the seismograms of local earthquakes are expected to be scarcely affected by both attenuation and surface layering. In this regard a spectral study of local earthquakes is emphasized in the region. For this sake, however, the local seismic network and observation system should have a wide dynamic recording range for computerized wave analysis and suitable event detection algorithm.

The wintering party of the 28th Japanese Antarctic Research Expedition (1986–

1988), JARE-28, established a local radio-telemetry seismic network along the Prince Olav Coast to study the local seismicity and characteristics of seismic waves in the Lützow-Holm Bay region (AKAMATSU *et al.*, 1988). In January 1988, the JARE-29 party expanded the network with an additional tripartite array in East Ongul Island. All array data are recorded by an FM analog data recorder with event detection logic based on signal to noise ratio of multibands.

During the period from June 1987 to September 1988, more than 11400 events were recorded.

In this paper, we show the network system. A total of the 4400 events, the data of which have been transported to Japan, are classified into five groups by their wave forms. Most of them are icequakes. However, among them we can identify four definite local earthquakes. Their epicenter locations are discussed briefly in relation to possible local geological structure around Syowa Station.

2. Network and System Design

The seismic network (Fig. 1) consists of two arrays with different size: a larger radio-linked array along the Prince Olav Coast and a smaller tripartite array in East Ongul Island (AKAMATSU, 1988).

The radio-telemetry seismic array consists of three sites, each with a 1-second 3-component seismometer; Syowa Station (SYO), Tottuki Point (TOT) and Langhovde (LAN). SYO is linked directly to the recording system at Earth Science Laboratory. TOT and LAN are located on the outcrops along the Prince Olav Coast, 15 and 20 km far from SYO, respectively, and are linked by radio-telemetry to the recording system.

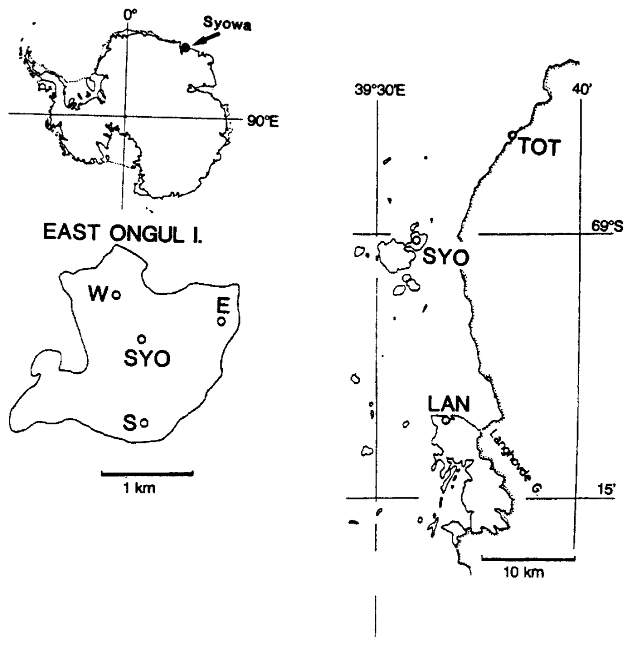

Fig. 1. Location of the seismic array. TOT and LAN are located on continental outcrops and linked to Syowa Station (SYO) by radio telemetry. The stations of E, S and W were also used in the preliminary observation during the period from February to May 1987.

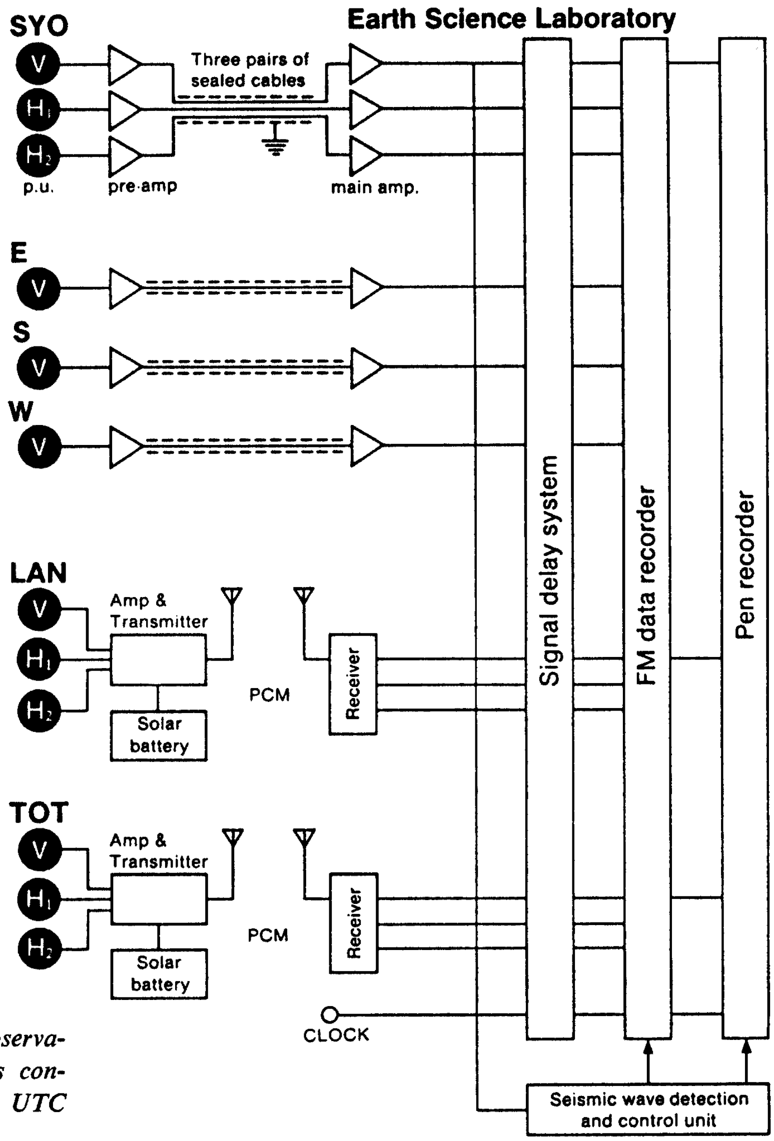

Fig. 2. Block diagram of observation system. CLOCK is connected to the recovered UTC from NNSS satellites.

The observation at TOT started in June 1987 and that at LAN in August 1987 after the transportation condition had become adequate for the snow vehicles to traverse on the sea ice.

The smaller tripartite array consists of three sites with 1-second vertical seismometers; E, S and W, as shown in Fig. 1. The distances between the sites are about 1.5 km. Each site is linked directly to the recording system. The observation of the tripartite array started in February 1988.

A preliminary observation was carried out at E, S, W and SYO in East Ongul Island from February to May 1987 to test the system. The radio-telemeters were set at E and S temporarily to investigate technical problems in setting the system and battery support (AKAMATSU, 1988).

The observational system is shown in Fig. 2. The telemetry system is 12-bits Pulse Code Modulation (PCM) of 200 Hz sampling with transmitting power of 1 W. The amplifier unit and transmitter need the power of 8.6 W, which is supplied by a

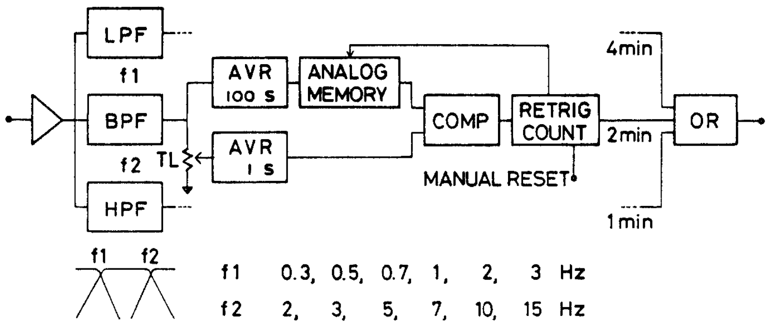

Fig. 3. Block diagram of seismic signal detection and control unit. Cutoff frequencies, f 1 and f 2, and threshold levels (TL) are selected to cope with the noise condition around Syowa Station. Signal (S) and noise (N) for each band are the outputs of averagers (AVR) with time constants of 1 s and 100 s, respectively. Recording times of LPF, BPF and HPF signals are 4, 2 and 1 min at least, respectively, and are prolonged for an event with longer duration time by the retriggerable counter (RETRIG COUNT). ANALOG MEMORY outputs the input level of every moment or that of fixed moment according to a command from RETRIG COUNT. It holds the noise level before event detected in order to record the whole seismic coda.

solar battery system with maximum power of 225 W produced by the solar panel module with the extent of 1 m×2 m. A zinc-air battery assembly (SAKAI *et al.*, 1981) was set as a spare battery for the winter season from May to July, during which the solar system is not available. However, the zinc-air battery was found useless because its electrolyte had frozen. As a result, LAN and TOT could not operate for several weeks in the wintertime of 1988.

The signal delay device consists of 12-bits A/D converters and D/A converters with 16 K-word memory and has 32.8 s delay time in case of 500 Hz sampling. Local earthquakes occurring within about 200 km can be recorded before the onset of *P* phase, even if it is detected by later *S* phase.

The seismic signal detection and control unit is made of C-MOS logic, and is based on signal to noise ratio of the multibands for the vertical component (AKAMATSU, 1977). The block diagram of the logic is shown in Fig. 3. The noise around Syowa Station is considered to consist of long-period microseism and characteristic short-period noise arising during blizzard. Both amplitude and predominant frequency of noise vary to a considerable extent with time according to weather condition. Small events, even when they are undetectable with small *S/N* ratio of a wide-band width, can be handled with clear signal separation from noise in narrow bands (AMBUTER and SOLOMON, 1974). The vertical component at SYO is monitored for event detection, because the system reliability and housing of transducers are superior to the other sites. The cutoff frequency of low-pass, band-pass and high-pass filters, f 1 and f 2, and threshold level for comparators, TL, are selected to cope with the noise condition around Syowa Station, that is, f 1 and f 2 are 1 and 7 Hz; TL for LPF, BPF and HPF signals are 2–3, 3–4 and 4–8, respectively.

An FM analog data recorder is used for data storage on the video cassette magnetic tape. Generally, in magnetic recording, digital systems are superior in terms of wide dynamic recording range and easy computerized processing. However, the dynamic recording range of the current recorder is great enough, that is, approximately 60 dB (tape speed of 1.2 cm with noise compensation), provided that the frequency range is limited to within 30 Hz required for seismic observation. Moreover, the easy reproduction of visible wave form is considered most important for the recording system at Syowa Station, because the normal functioning of the total system can be confirmed only by reproducing and checking the seismograms of teleseisms recorded simultaneously at each site (AKAMATSU *et al.*, 1988). Automatic computerized data processing also can be achieved through a GP-IB (IEEE-488 interface) in Japan.

The overall sensitivity is 1100–1400 V/cm/s in the frequency range of 1–30 Hz; the total dynamic range is 60 dB.

3. Data

More than 11400 events were recorded during the period from June 1987 to September 1988. However, we examined 4400 events recorded before February 1988 in this paper, because of limited transportation of data from Syowa Station to Japan. The 4400 events can be divided into five groups: local earthquake, teleseism, icequake of sea ice around the Ongul Islands, shock-type icequake of continental ice sheet and continuous vibration caused by glacier movement, by visual analysis of reproduced seismograms, as listed in Table 1.

In order to confirm the occurrence of local earthquakes, some examples of wave forms of the other groups are shown. Figure 4 shows an example of icequake located on the east coast of East Ongul Island by the small tripartite array of the preliminary observation. One third of the recorded events have similar wave forms; the occurrences seem to be related to sea ice condition and weather around the Ongul Islands. Therefore, they are possibly caused by fractures of sea ice near the Ongul Islands and are grouped as sea-ice shock in Table 1. It is difficult to pick up the sea-ice shocks occurring near SYO on the records of TOT and LAN because of their small amplitude. The thickness of sea ice around Syowa Station is usually less than 2 m, and restricts the upper bound of ice shock magnitude. On the contrary, many icequakes occurring near TOT or LAN can be detected at SYO. An example of seismograms is shown in Fig. 5. Considering their magnitudes, a majority of them

Table 1. Amounts of events in each group and maximum amplitude level at SYO.

Max. amplitude (μ cm/s)	>200	200–100	100–50	50–20	<20	Total
Sea-ice shock	24	126	249	659	418	1476
Icequake	13	52	109	589	1597	2351
Glacier movement	4	8	22	62	30	126
Teleseism	21	39	75	133	233	501
Local earthquake		1	1	2		4
Event total	62	226	456	1436	2278	4458

Ground noise	Electric noise	Noise total
97	54	151

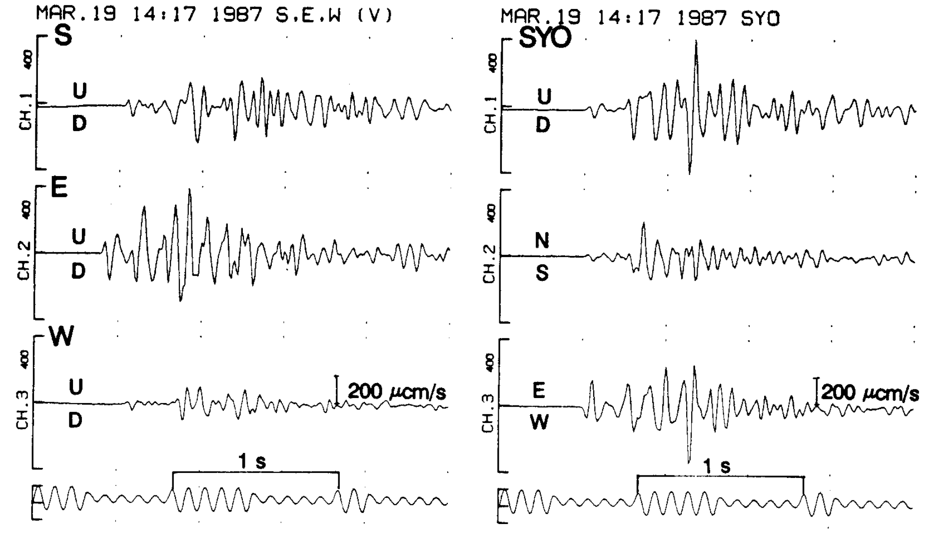

Fig. 4. An example of sea-ice shock occurring around Syowa Station. Left: vertical seismograms at S, E and W. Right: three-component seismogram at SYO. The event was recorded in the preliminary observation and located on the east coast of East Ongul Island. Note that the duration time is only a few seconds.

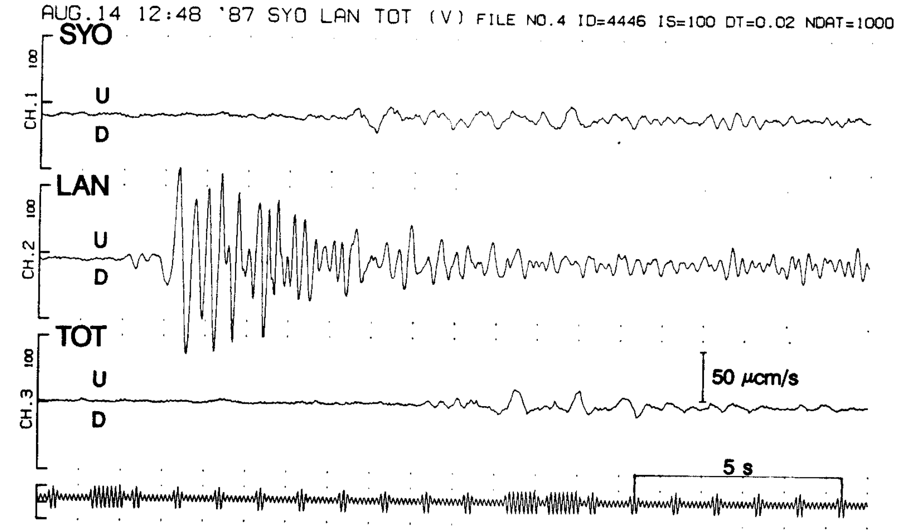

Fig. 5. An example of icequake in continental ice sheet occurring near LAN. Note the small amplitudes and low frequency at SYO and TOT.

is considered to be caused by the continental thick ice sheet up to 600 m (ITO and IKAMI, 1984) or the glaciers on the Prince Olav Coast. KAMINUMA and HANEDA (1979) grouped icequakes around Syowa Station into two types; Type I with a sharp initial phase and Type II with an obscure initial phase. Type I may correspond to sea-ice shock around the Ongul Islands and Type II may correspond to icequake on the continent across the Ongul Strait.

Figure 6 is an example of continuous vibration which is supposed to be caused by an glacial flow, inferred from the amplitudes distribution and duration time. In a typical case, it continues for more than 10 min and is thought to be related to glacier

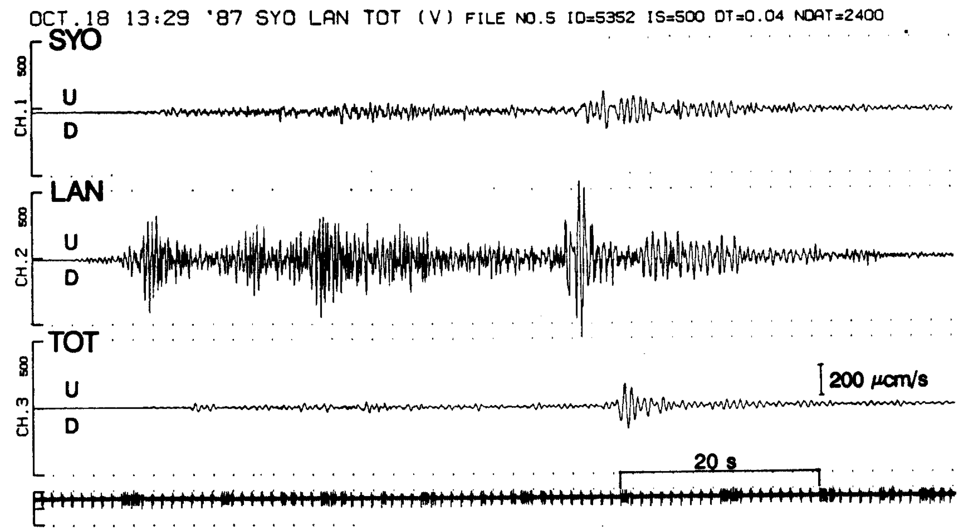

Fig. 6. An example of continuous vibration caused by the Langhovde Glacier movement.

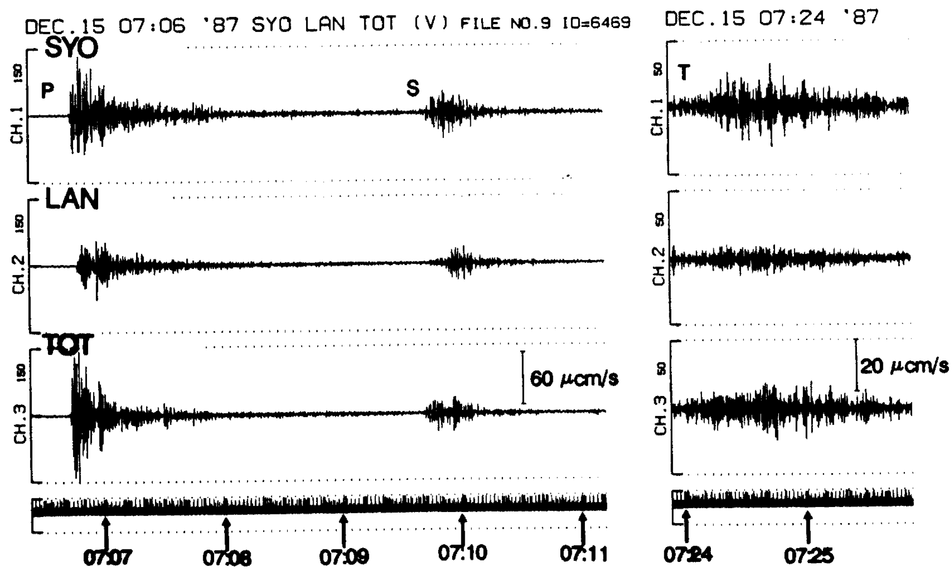

Fig. 7. An example of events at the Atlantic-Indian Rise about 2000 km north of Syowa Station. Note that amplitude scale for T phase is three times smaller than that for P and S phases.

surge.

Among the teleseisms, four events are followed by remarkable *T* phases. They are considered to occur near the Atlantic-Indian Rise about 2000 km north of Syowa Station (Sept. 22, 2042; Nov. 25, 2002; Nov. 26, 0040; Dec. 15, 0706, 1987, *S*-*P*= 2m55s–3m, *T*-*P*=17m, azimuth=N-NNW). An example of these events is shown in Fig. 7.

4. Local Earthquakes

Four definite local earthquakes were recorded by the system during the period from June 1987 to January 1988, as listed in Table 2.

Table 2. List of local earthquakes around Syowa Station.

ID No.	Day	Time	Magnitude	Source region
3089	Jun. 10	1936	2.6	Prince Olav Coast, 170 km NE of Syowa Station
5743	Nov. 07	0623	1.5	Lützow-Holm Bay, 50 km NW of Syowa Station
6599	Dec. 22	1136	1.0	
6622	Dec. 23	0654	0.9	Near Tama Glacier, 50 km NE of Syowa Station

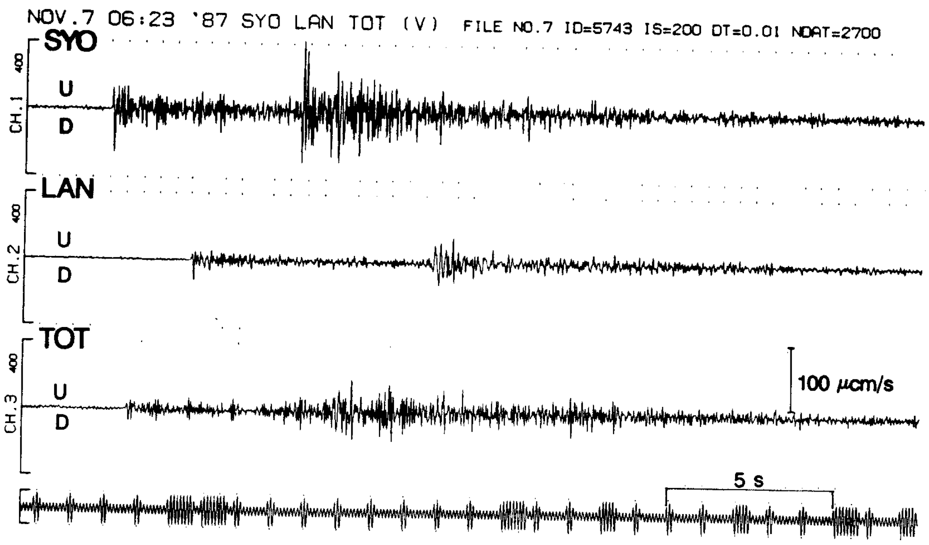

Fig. 8. Seismograms of local earthquake that occurred in Lützow-Holm Bay, 50 km northwest of Syowa Station. The source region is the northern extension of a possible fault inferred from a glacial valley on the sea floor.

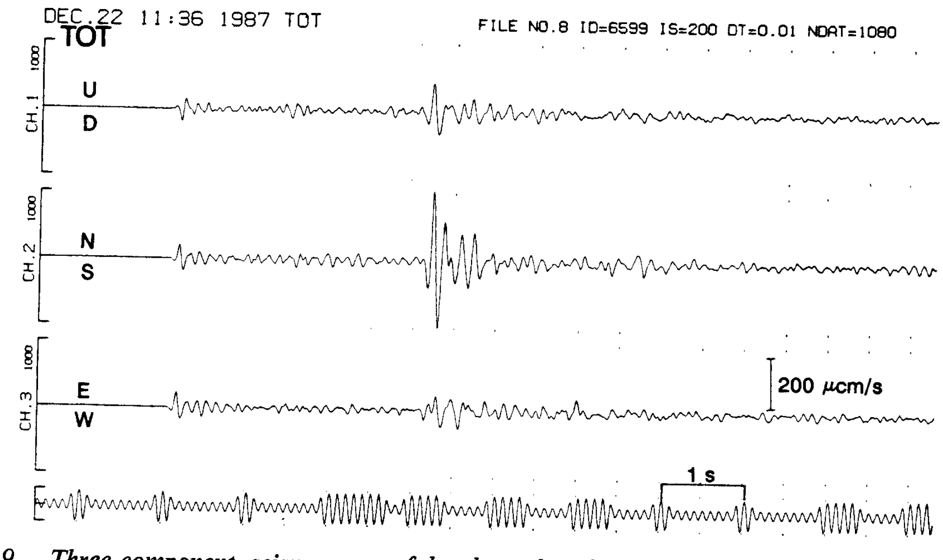

Fig. 9. Three-component seismogram of local earthquake observed at TOT. The event occurred at 50 km northeast of Syowa Station. This is the nearest seismogram to the source in the observation.

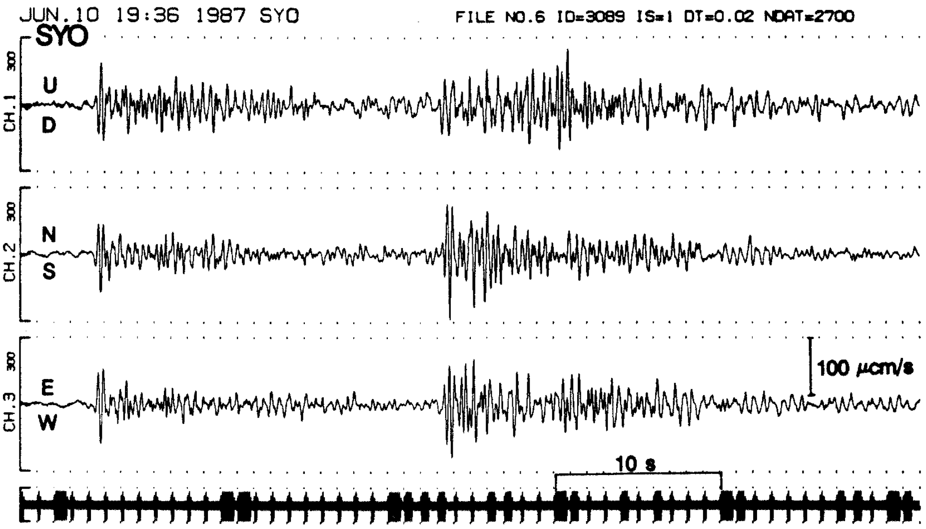

Fig. 10. Three-component seismogram of local earthquake observed at SYO. The event occurred at about 170 km northeast of Syowa Station. Ten earthquakes with similar wave forms were observed in the preliminary observation during four months from February to May 1987.

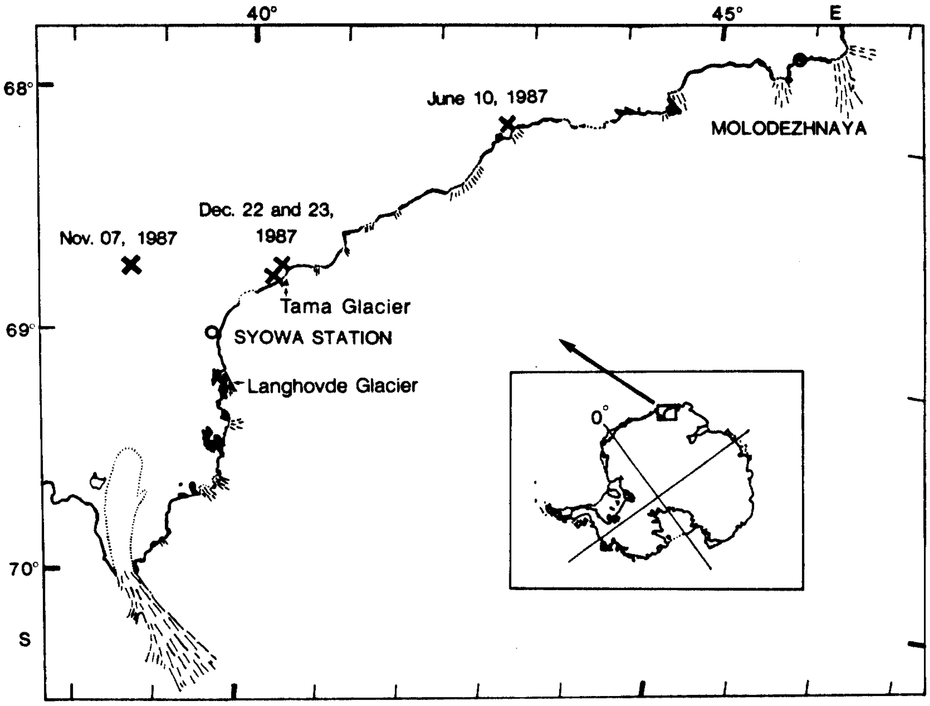

Fig. 11. Locations of hypocenters of shallow crustal earthquakes. Although the events on Dec. 22 and Dec. 23 occurred in the same location, the hypocenters are marked separately in the figure to show the existence of two events clearly.

The vertical seismograms of event on Nov. 7, recorded at the three sites; SYO, LAN and TOT, are shown in Fig. 8. Its aftershock was picked up on the seismogram of routine observation at SYO (Nov. 7, 0648, $M=0$). Figure 9 shows the 3-component seismogram of event on Dec. 22, observed at TOT. This seismogram has the shortest *S-P* time in the local earthquakes observed. Events on Dec. 22 and Dec. 23 have similar wave forms at all sites, indicating the same source location. Figure 10 is the 3-component seismogram of event on June 10 at SYO, which has 20 s *S-P* time. Nine events with similar wave forms were recorded by the preliminary observation during February to May 1987. Preliminary analysis of the events with 20 s *S-P* time was reported in the previous paper (AKAMATSU *et al.*, 1988).

The source locations of events in Figs. 8–10 were obtained with a velocity model estimated by the explosion seismic experiments (ITO and IKAMI, 1984; IKAMI *et al.*, 1984) as shown in Fig. 11. The source depths are assumed to be shallow, because the array configuration is not adequate for precise determination of depth. This limitation is coming from the distribution of coastal outcrops without ice coverage. It is evident, however, that these events are the shallow crustal earthquakes judging from their typical wave forms. The assumption of the source depth is considered reasonable because of the evidence that the source azimuths are nearly identical with the direction of *P* initial motions.

Local magnitudes in Table 2 are estimated with the formula for shallow event (WATANABE, 1971),

$$M=1.18\log(Av_{\max})+2.04\log R-4.14\,, \quad \text{for} \quad R<200\text{ km} \qquad (1)$$

where $Av_{\max}$ is maximum velocity amplitude in cm/s and R is focal distance in km. Equation (1) is obtained with the data of the Abuyama Seismological Observatory and its array stations of Kyoto University, which are located on the sedimentary layers in southwest Japan. Since there exist no sedimentary layers in the Prince Olav Coast region (ITO *et al.*, 1984; ITO and IKAMI, 1984), the surface amplification may be smaller than that in Japan by up to 2 factors. Therefore, the magnitudes in Table 2 are probably underestimated by 0.2–0.3.

5. Discussion

The source region of the events with 20 s *S-P* time is about 160–200 km northeast of Syowa Station. The basement of the Prince Olav Coast region, named the Lützow-Holm Complex, is known to have undergone a metamorphism different from the Rayner Complex around Molodezhnaya Station of U.S.S.R., 300 km northeast of Syowa Station (HIROI and SHIRAISHI, 1986). Although the boundary between the two complexes is not clear, several geological faults seem to exist in the coastal area. The local events must be located around the faults (AKAMATSU *et al.*, 1988) and suggest that faults can move under some tectonic conditions. The source region of the event on Nov. 7, 50–60 km northwest of Syowa Station, is on the northern extension of a possible fault, inferred from the glacial trough on the sea floor in Lützow-Holm Bay (MORIWAKI and YOSHIDA, 1983). Two micro earthquakes of Dec. 22 and 23 occurred near the Tama Glacier, about 50 km northeast of Syowa Station, on the Prince Olav Coast. It is suggested that glaciers are related with faults in the coastal region (MORIWAKI, 1986). The micro earthquakes also suggest the existence of faults near the Tama Glacier.

It is very interesting that source locations of all the events observed can be discussed in relation to possible faults in the Prince Olav Coast region. Since the distribution of active glaciers may reflect the topography and geological structure, local seismic activity and tectonics can be discussed in relation to the distribution of glaciers.

It is clear that the seismic detection algorithm based on band limited S/N ratios is very useful under the noise condition around Syowa Station. However, in order not to record sea-ice shocks with negligibly small amplitude, the algorithm should take the absolute amplitude level and duration time into account.

6. Conclusion

A telemetry seismic network was installed along the Prince Olav Coast around Syowa Station to study local seismic activity and characteristics of seismic waves in the Lützow-Holm Bay and Prince Olav Coast region. 4400 events were recorded during the period from June 1987 to January 1988. These events can be divided into five groups: icequake of sea ice around the Ongul Islands, icequake of continental ice sheet, continuous vibration caused by glacial movement or surge, teleseism and local earthquake. Four shallow crustal earthquakes were located and discussed in relation to possible faults around Syowa Station inferred from geological and geographical studies. Other 10 local earthquakes with the similar wave forms were detected by the preliminary observation and routine observation carried out at Syowa Station. The East Antarctic shield has been considered to be an aseismic area. It becomes clear, however, that faults can move seismically under some tectonic condition.

The seismic observation with the radio-telemetry network will be continued until the end of 1989 by JARE-30.

Acknowledgments

The observation network was constructed by JARE-28 and JARE-29. The authors express their sincere thanks to Dr. Yoshikuni OHYAMA, leader of the wintering party of JARE-28, and Prof. Okitsugu WATANABE, leader of JARE-29. The authors are grateful to all the members of the wintering party of JARE-28 and JARE-29, especially Dr. Y. MIYATA, Messrs. H. BABA, K. SONE, K. NAKAYAMA, H. TAKABE, H. SUGAWARA and K. INAMORI for their assistance and cooperation.

The authors also express their hearty thanks to Dr. Kazuo SHIBUYA of National Institute of Polar Research and Prof. Takao HOSHIAI, leader of JARE-28, for their encouragement for this study.

The authors also thank Ms. Y. SHUDO and Mrs. A. TAKAHASHI for preparing the manuscript.

The data were processed by a MELCOM 70MX/3000 system at Disaster Prevention Research Institute of Kyoto University.

References

ADAMS, R. D., HUGHES, A. A. and ZHANG, B. M. (1985): A confirmed earthquake in continental Antarctica. Geophys. J. R. astr. Soc., **81**, 489–492.

AKAMATSU, J. (1977): Sumiyama zishin kansokushitu ni okeru zishin kansoku (Seismic observation at the Sumiyama Seismic Station). Kyoto Daigaku Bousaikenkyusho Nenpou (Annu. Disas. Prev. Res. Inst., Kyoto Univ.), **20 B-1**, 13–19.

AKAMATSU, J. (1980): Attenuation property of seismic waves and source characteristics of small earthquakes. Bull. Disas. Prev. Res. Inst., Kyoto Univ., **30**, 53–80.

AKAMATSU, J. (1986): Seismic zoning and seismic ground motion in the southern part of Kyoto, Southwest Japan. Bull. Disas. Prev. Res. Inst., Kyoto Univ., **36**, 1–42.

AKAMATSU, J. (1988): Nankyoku Syowa Kiti ni okeru teremeta zishin kansoku no houhou to mondaiten (Some problems on seismic observation with a radio telemetry network around Syowa Station, East Antarctica). Kyoto Daigaku Bosaikenkyusho Toshi Taishin Senta Kenkyu Houkoku (UEHR Rep., DPRI, Kyoto Univ.), **2**, 142–151.

AKAMATSU, J., YOSHIKAWA, S. and KAMINUMA, K. (1988): Preliminary report of local seismic activity around Syowa Station, East Antarctica. Proc. NIPR Symp. Antarct. Geosci., **2**, 1–6.

AKI, K. (1989): Koda-Q tekutonikkusu teki katsudodo no chikyu butsuri teki shihyo (Coda-Q as a geophysical indicator of tectonic activity). Kokuritu Bosai Kagaku Gizyutu Senta Kenkyu Sokuho (Res. Note Natl Res. Cent. Disas. Prev.), **80**, 33–85.

AMBUTER, B. P. and SOLOMON, S. C. (1974): An event recording system for monitoring small earthquakes. Bull. Seism. Soc. Am., **64**, 1181–1188.

HIROI, Y. and SHIRAISHI, K. (1986): Syowa Kiti syuhen no chisitu to ganseki (Geology and rocks around Syowa Station). Nankyoku no Kagaku, 5 Chigaku (Science in Antarctica, 5 Earth Sci.), ed. by Natl Inst. Polar Res. Tokyo, Kokon Syoin, 45–84.

IKAMI, A., ITO, K., SHIBUYA, K. and KAMINUMA, K. (1984): Deep crustal structure along the profile between Syowa and Mizuho Stations, East Antarctica. Mem. Natl Inst. Polar Res., Ser. C (Earth Sci.), **15**, 19–28.

ITO, K. and IKAMI, A. (1984): Upper crustal structure of the Prince Olav Coast, East Antarctica. Mem. Natl Inst. Polar Res., Ser. C (Earth Sci.), **15**, 13–18.

ITO, K., IKAMI, A., SHIBUYA, K. and KAMINUMA, K. (1984): Upper crustal structure beneath the Ongul Islands, East Antarctica. Mem. Natl Inst. Polar Res., Ser. C (Earth Sci.), **15**, 3–12.

KAMINUMA, K. (1976): Seismicity in Antarctica. J. Phys. Earth, **24**, 381–395.

KAMINUMA, K. and HANEDA, T. (1979): Nankyoku Syowa Kiti de kansoku sareta hyoshin (Icequakes around Syowa Station, Antarctica). Nankyoku Shiryô (Antarct. Rec.), **65**, 135–148.

KOGAN, S. D., PASECHIK, I. P. and SULTANOV, D. D. (1965): A seimic map of Antarctica. Bull. (Izv.) Acad. Sci. USSR, Geophys. Ser., **2**, 81–83.

MORIWAKI, K. (1986): Ryuttsu Horumu Wan oyobi Purinsu Orahu Kaigan chiiki no rogan no chikei (Topography of outcrops in Lützow-Holm Bay and Prince Olav Coast Region). Nankyoku no Kagaku, 5 Chigaku (Science in Antarctica, 5 Earth Sci.), ed. by Natl Inst. Polar Res. Tokyo, Kokon Shoin, 127–130.

MORIWAKI, K. and YOSHIDA, Y. (1983): Submarine topography of Lützow-Holm Bay, Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **28**, 247–258.

SAKAI, T., KUMETA, M., HAGINO, H. and TOYOTA, K. (1981): Kyokuti dengenyou aen-kuuki denchi (Zinc-air battery for use as a power source in the polar region). Sanyo Technic. Rev., **13**, 113–117.

WATANABE, H. (1971): Kinchi zishin no magunichudo (Determination of earthquake magnitude at regional distance in and near Japan). Zisin (J. Seis. Soc. Jpn.), 2nd ser., **24**, 189–200.

(Received April 11, 1989; Revised manuscript received May 16, 1989)